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CHAPTER FIVE

MECHANICAL CONSIDERATIONS

5.2 MECHANICAL AND THERMAL PROPERTIES OF COMPOSITE CONDUCTORS

R. M. Scanlan LBNL

5.2.1 Composite Conductors, Mechanical

Modern superconductors are composites of the superconductor together with other elements that are fabricated with the superconductor and are an integral part of the composite. These elements usually include a high purity normal metal such as Cu, Ag, Al, as well as structural materials such as stainless steel. In the elastic range, the modulus can be estimated well from a simple rule of mixtures. For NbTi alloy based superconductors, the mechanical strength is usually dominated by the superconductor component which is heavily cold worked and precipitation hardened in order to optimize the superconducting critical current density. Example stress-strain relations[1] are shown in Fig. 1. The modulus for different compositions can be estimated using the rule of mixtures, eq. 1.

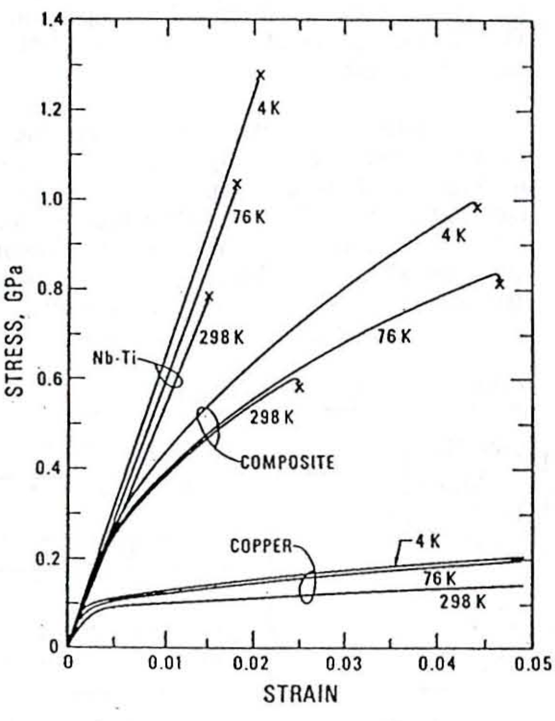

Fig. 1 Stress-strain characteristic for a typical mulitfilamentary NbTi conductor and its components containing 36vol.% NbTi and 64 vol. % Cu

For Nb_3Sn and other A15 superconductors the effective strain limit of the composite is determined by the brittle nature of the superconductor which fractures at about 0.2% tensile strain. The useful strain limit of the composite conductor is extended by the matrix which places the Nb_3Sn in compression due to the differential thermal expansion (5.2.2). The overall strain state[2] can be estimated from the rule of mixtures as is illustrated in Fig. 2 using the component thermal expansion properties.

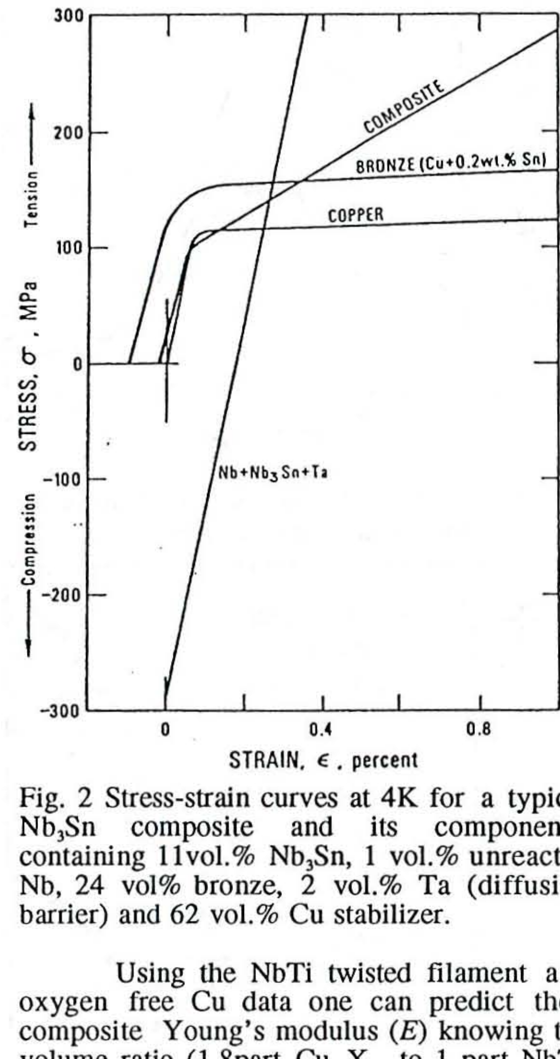

Fig. 2 Stress-strain curves at 4K for a typical Nb_3Sn composite and its components, containing 11vol.% Nb_3Sn, 1 vol.% unreacted Nb, 24 vol% bronze, 2 vol.% Ta (diffusion barrier) and 62 vol.% Cu stabilizer.

Using the NbTi twisted filament and oxygen free Cu data one can predict their composite Young's modulus (*E*) knowing the volume ratio (1.8part Cu, X_{cu}, to 1 part NbTi, X_{NbTi}) using the rule of mixtures relationship

$$E_{comp.} = \frac{X_{Cu}E_{Cu} + X_{NbTi}E_{NbTi}}{X_{Cu} + X_{NbTi}} \qquad (1)$$

5.2.2 Composite Conductors, Thermal

Thermal conductivity values vary over several orders of magnitude for the different materials involved in superconducting magnet windings. They also vary by over an order of magnitude for the individual materials over the temperature range from 300K to 5K (see Fig. 1 of 5.1) Thermal conductivity of pure metals can vary significantly depending on the state of cold work and of purity. Fig. 3 shows both effects for copper.

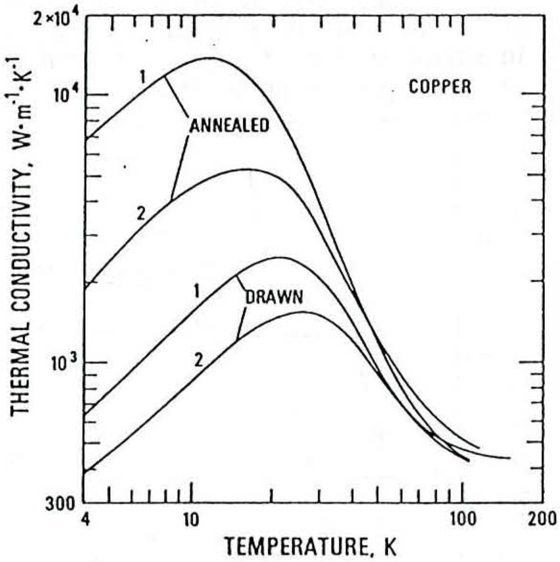

Fig. 3 Thermal conductivity changes due to cold work and purity variation[3]

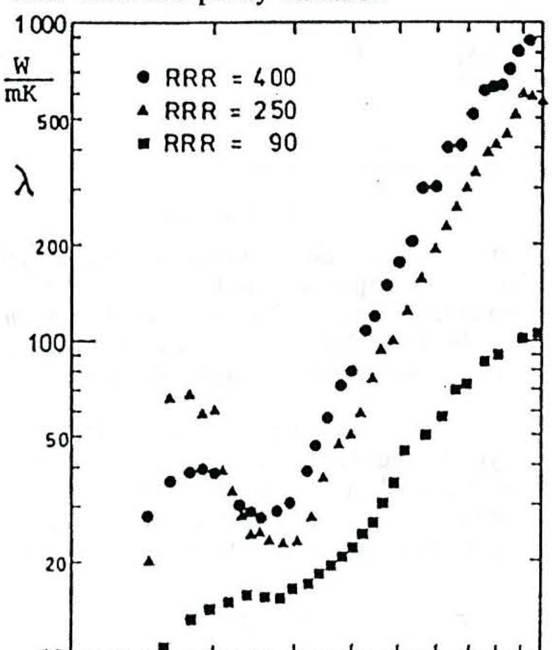

Fig. 4 Thermal conductivity of Nb[4] for various purity levels.

Figure 4 shows the purity effect for Nb while Fig. 5 shows the influence of magnetic field on Nb.

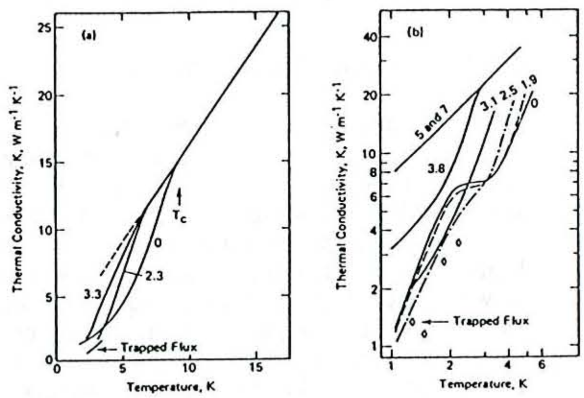

Fig. 5 Influence of magnetic field on thermal conductivity of Nb

Given the wide variation of thermal conductivity one needs to know the state of cold work and purity before making calculations over extended temp. ranges. Direct measurement of the as delivered material is best.

Thermal expansion coefficients likewise can vary significantly between materials and as a function of temperature (see Fig. 3, Sec. 5.1) Several measurements for composite coil sections have been reported and are shown in Table 1. The rule of mixtures usually gives good results provided that the composite does not delaminate.

Table 1- contraction of composites

Coil	ΔT (K)	%contraction
NbTi/Kapton		
SSC-inner, [5]longitudinal	294-4	0.26
radial	294-4	0.42
Nb_3Sn/[6] fiber-glass-epoxy		
outer	293-77	0.26
inner	293-77	0.29

References

1. R.P. Reed and R.P. Mikesell, Low Temperature Tensile Behavior of Copper Stabilized NbTI Superconductor Wire, Adv. in Cryogenics, V.22, Plenum 1977 pp 463-471

2. D.S.Easton et al, A Prediction of the Stress State in Nb_3Sn Superconducting Composites, J. Appl. Phys. 51, 2748ff, 1980
3. R.P.Reed and A.F.Clark, Materials at Low Temperatures, American Society for Metals, Metals Parks, OH., 1983, p 147.
4. Courtesy Wuppertal University
5. Courtesy C. Goodzeit, Brookhaven Nat. Lab.
6. D. Dell'Orco and H Tsui, Mechanical Measurements on D20 Nb_3Sn Cables ,1994, SC-MAG 465.